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ONE DIMENSIONAL MODEL FOR SUPERSONIC COIL

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ONE DIMENSIONAL MODEL FOR SUPERSONIC COIL

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Zhan Jiping, WangChengdong, and Zhuang Qi

ABSTRACT

This article considers the key chemical kinetics processes in DOIL systems. It sets up a one dimensional, pre- mixed, simplified model, calculating, in COIL systems, such parameters as small signal gains, output powers, power to volume ratios, chemical efficiencies, and so on, following along with changes in cavity pressures, cavity temperatures, and operating material composition proportions. In conjunction with this, it gives optimum operating conditions for supersonic COIL.

KEY WORDS Supersonic COIL Model

1 INTRODUCTION

Chemical oxygen iodine lasers (COIL) use such advantages as high power, high efficiency, short wave length, and so on, to manifest huge potential in fields of application. Basic research associated with COIL possesses very important significance. However, theoretical models relating to continuous wave COIL are very few. Moreover, they are only subsonic [1].

This article uses a one dimensional pre-mixed simplified model, studying--in supersonic COIL systems--small signal gains, power to volume ratios, output powers, chemical efficiency, as well as lasing zone length following along with changes in such parameters as cavity temperature, cavity pressure, operating material composition ratios, and so on.

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* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

2 MATHEMATICAL MODELS

Option is made for the use of one dimensional pre-mixed models, simplifying gas mixing processes in systems. Fig.1 is a model schematic diagram. In it, assume:

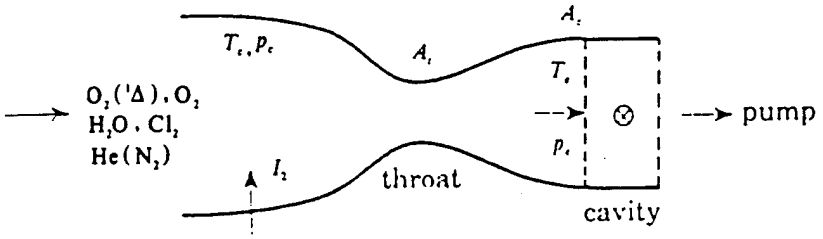

Fig. 1 Schematic drawing of one dimension supersonic oxygen－iodine chemical laser model (laser propagates in the direction perpendicular to the paper)

1) The model is a one dimensional pre-mixed model. Constituents are uniformly mixed at the initial moment. Concentration distributions associated with height direction and light axis direction are not considered.

2) Supersonic expansion processes are adiabatic isoenthalpic expansion, satisfying $T_e/T_c=(p_e/p_c)^{(\gamma-1)/\gamma}$.

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3) During expansion processes, temperature changes have extremely small influences on C_p. c_{p_i} is seen as a constant.

4) Supersonic expansion processes are frozen flow movements. There are no chemical reactions. There are no phase changes. Before entering into light cavities, the various constituents are maintained invariable.

5) During light output processes, phase changes as well as pressure and temperature changes given rise to because of constituent changes and energy changes are not considered.

6) Light cavity shapes are infinitely large parallel planar cavities.

Chemical kinetic processes, after entering optical cavities, opt for the use of chemical kinetic models put forward in reference [2] as well as reaction speed constants--primarily including I_2 dissociation, $O_2(^1\Delta)$ and I* atom transmission energy, I* as well as $O_2(^1\Delta)$ quenching processes, I* spontaneous radiation, as well as I atom triple combination processes.

Control equations are as follows

$$\frac{dN_i}{dt} = \sum W_{pi} - \sum W_{di} \tag{1}$$

$$\frac{dN_1}{dt} = \sum W_{p1} - \sum W_{d1} + \alpha f \tag{2}$$

$$\frac{dN_{1^*}}{dt} = \sum W_{p1^*} - \sum W_{d1^*} - \alpha f \tag{3}$$

$$\frac{df}{dt} = c(\alpha - \alpha_{th}) f \tag{4}$$

and

$$P = hV\alpha f \tag{5}$$

In this, $\alpha = \sigma\{[I^*] - 0.5[I]\}$, $\sigma = 1.29 \times 10^{-16} T^{-1/2}$, $\alpha_{th} = -\ln r_1 r_2 / 2L$.

In the formulae above, N_1, N_{1^*}, N_i respectively represent the particle number densities associated with I atom, I* atom, and other constituents. $W_{p1}, W_{d1}, W_{p1^*}, W_{d1^*}, W_{pi}, W_{di}$ respectively stand for I atom, I* atom, and other component particle number densities due to changing speeds of reaction production and consumption. α is a gain coefficient. α_{th} is the

threshold value gain constant. σ is the I atom stimulated emission cross section. T is the I atom level motion temperature. f is the photon flux density. P is the volume to power density. $r_1 r_2$ are cavity mirror reflection factors. L is optical cavity length. h is optical cavity height. V is the overall volume of the light output area.

Assuming l is the lasing zone length in the direction of flow movement, then, the light output zone overall volume is V=hLl. Output power is

$$P_{out} = \int PdV = hL \int Pdl \tag{6}$$

Chemical efficiency is

$$\eta_c = \frac{P_{out}}{P_\Delta} \tag{7}$$

In this, P_Δ is $O_2(^1\Delta)$ energy carrying efficiency.

During calculation processes, T_c is generally taken as 298K. With regard to different gas composition ratios, specific heat ratios γ can be calculated out. Selecting p_e/p_c values, it is possible to obtain different optical cavity temperatures T_e. Among calculation results given in the text below, the temperature changes in Fig.2 are nothing else than ones arrived at in the same way. The two temperatures in Fig.3--T_e = 189K and 156K--respectively correspond to pressure ratios $p_e p_c$ = 1/5 and p_e/p_c = 1/10. Fig.4 and Fig.5 are both arrived at under conditions where p_e/p_c = 1/5 and T_e = 189K. Here, what must also be explained is: 1) Small signal gain is a function of location coordinates in optical cavities along the gas flow movement direction. As a result, we only need to select maximum values in order to explain problems. 2) When calculating lasing area length, we select a distance from initial light output to where

volume to power ratios fall to 5% of peak values in the direction of gas flow movements.

3 RESULTS AND DISCUSSION /495

1. Influences of Cavity Temperatures on Small Signal Gains

Table 2 shows small signal gain coefficients under the same cavity pressures and different I_2 ratio conditions following along with changes in cavity temperatures. From the Fig., it is possible to see that, no matter what I_2 ratios are, small signal gain coefficients are always increasing, following along with drops in temperature. From the Fig.'s, it is also possible to

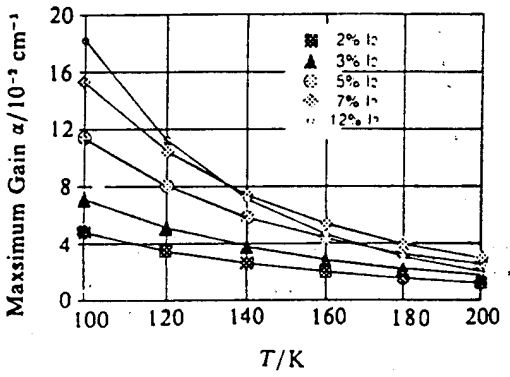

Fig. 2 Variation of gain coefficient *vs* cavity temperature (partial pressure of O_2 in the cavity is 111Pa)

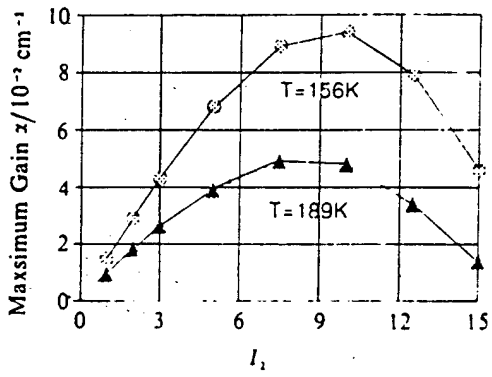

Fig. 3 Variation of gain coefficient *vs* percentage of I_2 under different cavity temperatures (partial pressure of O_2 in the cavity is 133Pa)

see that, within a certain range, gain coefficients α follow I_2 ratio increases and enlarge. Moreover, in the Fig., the two curves representing different iodine ratios exhibit mutual crossing phenomena. The explanation is that, following along with unceasing increases in I_2 ratios, coefficient constants do not enlarge without limit, but reach a maximum value when at a certain I_2 ratio value. This I_2 ratio value changes along with temperatures. Fig.3, then, displays this result. In Fig.3, the upper and lower curves respectively stand for situations where cavity temperature T is 156K and 189K. When 156K, the

corresponding maximum gain coefficient I_2 ratio is 10%. However, when 189K, the corresponding maximum gain coefficient I_2 ratio is 7%.

From the temperature relationship expressions put forward above for isoenthalpic adiabatic expansion, it is possible to know that optical cavity temperatures are determined by expansion process pressure ratios as well as gas specific heat ratios. As a result, it is possible--through changing optical cavity and spray nozzle structures in order to change expansion process pressure ratios--to also be able to go through alterations in dilution agents as well as ratios in order to change gas specific heat ratios, thereby achieving the objective of lowering optical cavity temperatures.

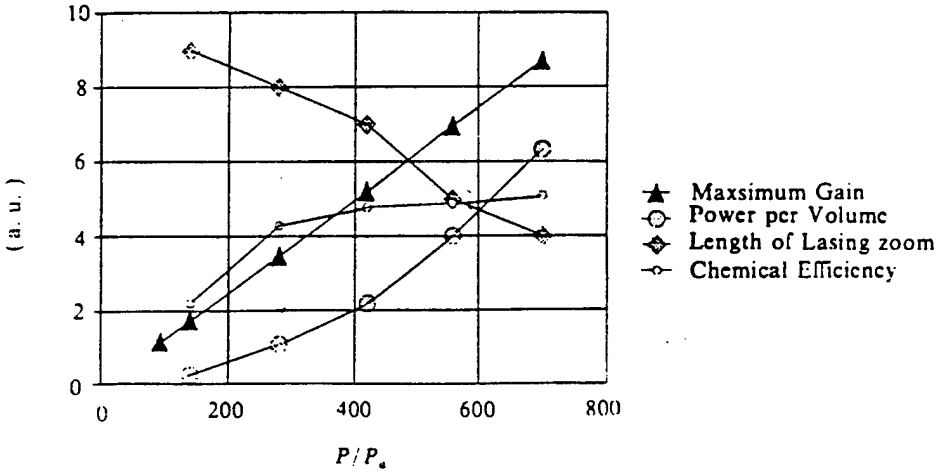

Fig.4 Variation of laser operating parameters *vs* cavity pressure

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2. Influences of Cavity Pressure on Systems

The influences of cavity pressure on laser performance can be seen from Fig.4. Within our range of designs, gain coefficients are almost a directly proportional function with regard to pressure. Power follows increases in pressure and goes up even faster. Chemical efficiency follows increases in pressure and increases to a stable value. However, this certainly does not make it clear that the higher system pressures

are the better. From Fig.4, it is possible to see that, following along with cavity pressure increases, the light output zone length gets shorter and shorter. After light output zone length is shortened to a certain level, in experiments, cavity adjustments will become very difficult, even to the point of being impossible. This then explains why optical cavity pressures go up, but output powers fall.

3. Influences of I_2 Ratios on Systems

The influences of I_2 ratios on laser properties are as shown in Fig.5. Following along with increases in I_2 ratios, gain coefficients--from small to large--arrive at a maximum value. At this time, optimum I_2/total oxygen is 10% or $I_2/O_2(^1\Delta)$ is 20%. When I_2 ratios continuously increase, gain coefficients begin to go down. This and I_2 molecule dissociation turn into I atoms. Generally, there is a need for 3-5 stimulated state O_2 molecule test results to agree. From Fig.5, it is possible to see that, when I_2 ratios are 1%-2% of total oxygen, system chemical efficiency and output power reach relatively high levels. Moreover, light output zone lengths at that time also lay within experimentally acceptable ranges. These are relatively good test conditions. When I_2 ratios increase, although gain coefficient numbers and power to volume ratios increase, laser chemical efficiencies and power outputs, however, show no clear increases --even to the point of there being drops. Moreover, optical output zone lengths still very greatly shorten. Therefore, overall levels are not high. These are not optimal test conditions.

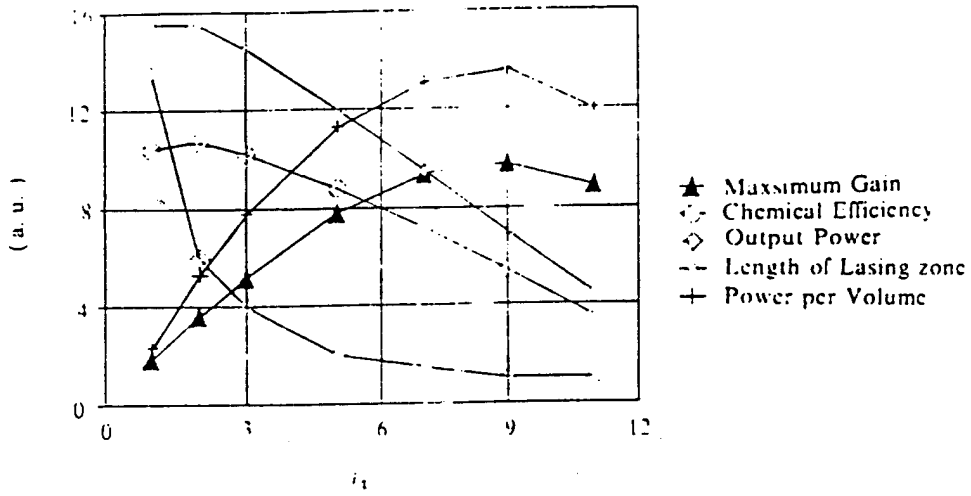

Fig. 5 Variation of laser operating parameters *vs* percentage of I_2
(partial pressure of O_2 in cavity is 133Pa)

To summarize what was discussed above, dropping cavity temperatures, raising cavity pressures, and raising iodine ratios within a certain range have influences on systems which all make system gain coefficients and specific powers increase. Moreover, they make light output zone lengths shorten. However, in reality, these three influences are the same. Based on gas state equations, dropping temperatures are capable of making various system component concentrations go up. Moreover, seen from the point of view of chemical kinetic processes, dropping temperatures makes I_2 molecules dissociate to become I atoms with quickened speeds and energy transmission speeds between $O_2(^1\Delta)$ and I atoms. As a result, I reversal processes are beneficial. Moreover, raising optical cavity pressures is simply causing the various system constituent concentrations to increase in accordance with ratios. Obviously, the former is advantageous to the latter. As far as changing I_2 ratios is concerned, although it is capable of increasing iodine concentrations in the system. $O_2(^1\Delta)$ concentrations do not increase. As a result, the ill effects this brings with it--besides causing light output zone lengths to shorten--at the same time also make output powers and chemical efficiencies drop. Because of this, we reach the

conclusion that one should use dropping system temperatures as a way to increase gain coefficients.

Due to the fact that there have still been no domestic reports on supersonic oxygen iodine chemical lasers, as a result, our model calculation results cannot be compared to experimental results. However, using results for calculations associated with the model in question for subsonic situations--besides differences in lasing zone length being comparatively large--other data all matched up relatively well.

4 CONCLUSIONS

Making use of simplified, one dimensional, pre-mixed models, simulations were done of supersonic oxygen iodine chemical lasers, calculating the influences of temperatures, pressures, and gas composition ratios in optical cavities on gain coefficients, power to volume ratios, chemical efficiencies, output powers, and light output zone lengths. The lower temperatures were in volumes and the higher pressures were, the more beneficial it was with regard to increasing gain, specific powers, output powers, and chemical efficiencies. However, temperatures that were too low and pressures that were too high led to shortening of light output zone lengths and were not advantageous to experiments. As far as I_2 ratios being approximately 10% of total oxygen is concerned, systems reached maximum small signal gain coefficients. When I_2 ratios were 1%-2%, chemical efficiencies and output powers of systems were optimal. At this time, light output zone lengths were also relatively appropriate. These were optimal experimental conditions.

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